PRESSURE CONTROL METHOD

The present invention relates to a pressure control method, particularly, although not exclusively, for a vacuum chamber of a semiconductor or a flat panel display manufacturing assembly.

Figure 1 shows a vacuum system having a chamber 12, with volume V_0, and a pressure control system 10 for controlling the pressure in the chamber. A vacuum pump 14 having a pumping speed S_{pump} is connected to a chamber outlet 16 via a duct 18 for evacuating gas from chamber 12. A valve 20 with variable conductance C_{valve} controls gas flow from chamber 12 to pump 14. Valve 20 is usually a throttle valve, as shown, having a moveable vane for changing C_{valve}. A pressure gauge 22 monitors the pressure P in chamber 12 and a pressure control unit 24 controls C_{valve} according to the monitored pressure P. The flow of process gas at a mass flow rate Q_{in} into chamber 12 is controlled by mass flow controller 26. Process gas is evacuated from chamber 12 at a mass flow rate Q_{out}, which is determined by the product of the pressure in the chamber and the effective pumping speed S_{eff}. The effective pumping speed is:

$$S_{eff} = \frac{1}{\dfrac{1}{S_{pump}} + \dfrac{1}{C_{System}} + \dfrac{1}{C_{Valve}}}$$

where C_{system} is the conductance of the vacuum system upstream of the valve.

In operation, pump 14 evacuates chamber 12 to a predetermined low pressure and pressure control system 10 incrementally increases the pressure in chamber 12 to allow each processing step to be performed at its required pressure. Pressure change occurs according to:

$$\frac{\partial P}{\partial t} = \frac{Q_{In} - Q_{out}}{V_0}$$

Accordingly, when C_{valve} is decreased to a predetermined conductance, the effective pumping speed is decreased, and therefore Q_{out} decreases. A reduction in Q_{out} means that the mass of gas in the chamber increases, and therefore chamber pressure increases. It should be noted though that since the chamber pressure increases when S_{eff} decreases (and Q_{out} = pressure x S_{eff}), the rate of change of chamber pressure decreases until it stabilises at a steady pressure. Accordingly, a reduction in C_{valve} to a predetermined conductance causes the pressure to increase and stabilise at a set pressure. The change in C_{valve} required for each incremental increase in pressure can be predetermined by experimentation or by modelling. C_{valve} is changed by altering the position of, for instance, a vane of the valve mechanism.

The time taken for a pressure increase to occur depends on the time it takes for valve 20 to change to a predetermined conductance; and the rate of pressure increase for a fixed valve position and process gas mass flow rate (i.e. the time taken for the pressure to increase once the valve has been changed to the predetermined conductance). The first factor is dependent on the specific design of the valve and is typically very low (less than two seconds). The second factor is dependent on the mass flow rate into the system (Q_{in}), the mass flow rate of the system (Q_{out}) and the volume of the chamber V_0.

For instance, as shown in Figure 2, if a chamber pressure of 2.5 mbar is required for a specific processing step, the valve is set to a preset position so that C_{valve} is decreased from 850 m^3/hour to 50 m^3/hour. Consequently, pressure P increases from 0.1 mbar to 2.5 mbar. In the example shown in Figure 2, V_0 is relatively small and Q_{in} is relatively high, and therefore pressure response time is limited by the response time of the valve. Accordingly, the pressure in the chamber reaches the

required pressure of 2.5 mbar after 2 seconds i.e. the time taken for the valve 20 to reach its preset position.

However, if V_0 is relatively high or Q_{in} is relatively low, pressure response time is increased. One type of chamber where V_0 is generally large is a chamber used for manufacturing flat panel displays. An example of slow pressure response time in a chamber is shown in Figure 3. Figure 3 shows pressure increase for a system where V_0 is 100 litres and Q_{in} is 2 standard litres per minute. It will be seen that valve 20 reaches its preset position after about two seconds, but pressure P does not reach the required pressure until about 35 seconds.

It is desirable to provide a pressure control system and method capable of reducing pressure response times, particularly in chambers where V_0 is relatively high or Q_{in} is relatively low.

The present invention provides a method of setting the pressure in a chamber of a vacuum system to a required pressure, the system comprising a pressure control system including a pump for evacuating gas from the chamber and a flow controller for allowing the flow of gas into the chamber, the method comprising setting an initial flow out of the chamber for achieving a pressure above the required pressure so as to increase the rate of pressure increase, the initial flow occurring over a transient period which does not allow the pressure to exceed the required pressure, and setting a preset flow out of the chamber after the transient period has elapsed for achieving and maintaining the required pressure.

Other preferred aspects of the invention are defined in the accompanying claims.

In order that the present invention may be well understood, several embodiments thereof, which are given by way of example only, will now be described with reference to the accompanying drawings, in which:

Figure 1 shows a typical vacuum system;

Figure 2 is a graph showing chamber pressure and C_{valve}, against time, for a prior art pressure control method;

Figure 3 is another graph showing chamber pressure and C_{valve}, against time, for a prior art pressure control method;

Figure 4 is a graph showing chamber pressure and C_{valve}, against time, for a pressure control method according to a first embodiment of the present invention;

Figure 5 is a graph showing chamber pressure and C_{valve}, against time, for a pressure control method according to a variation of the first embodiment;

Figures 6 and 7 show two variations of the vacuum system shown in Figure 1;

Figure 8 shows a vacuum system for use with a method according to a second embodiment of the present invention;

Figure 9 is a graph showing chamber pressure and gas flow into the chamber, against time, for a pressure control method according to the second embodiment of the present invention;

Figure 10 shows a variation of the method shown in Figure 9;

Figure 11 shows a vacuum system for use with a method according to a third embodiment of the present invention;

Figures 12 to 15 show variations of vacuum systems for use with the methods of the first to third embodiments;

Figure 16 shows a vacuum system for use with a method according to a fourth embodiment of the present invention; and

Figures 17 and 18 show variations of the vacuum system shown in Figure 16.

As indicated above, the rate of pressure increase in a chamber of a vacuum system is:

$$\frac{\partial P}{\partial t} = \frac{Q_{In} - Q_{out}}{V_0}$$

V_0 is constant for any given vacuum system and the difference between the flow of gas into and out of the chamber controls the build up of gas in the chamber and hence the rate of pressure increase. In the typical system shown in Figure 1, the flow of gas out of the chamber (Q_{out}) is controlled by changing the valve conductance. When an increase in pressure is required the valve conductance is set to the predetermined conductance and the pressure is allowed to increase gradually and to stabilise at the required pressure (see Figure 3). In the embodiments, an initial flow into (Q_{in}) and/or out (Q_{out}) of the chamber 12 is set to achieve a pressure above the required pressure so as to increase the rate of pressure increase. The initial flow occurs over a transient period and is selected so that the pressure does not exceed the required pressure. In this way, pressure increase in the chamber is quicker. Preferably, the initial flow is reduced to the predetermined flow when the required pressure is attained, to stabilise the chamber at the required pressure. Alternatively, the initial flow can be reduced to the predetermined flow before the required pressure is attained, and although the pressure increase would not be as quick as the preferred method, it would still be faster than the prior art method.

In a first pressure control method illustrated by Figure 4, the valve is set to a preset conductance of 50 m^3/hour. Such a valve conductance gradually increases the pressure in the prior art to a required pressure of 2.5 mbar after about 35 seconds,

as shown by the prior art response curve superimposed on the graph. In the embodied method, C_{valve} is reduced to an initial conductance which is well below the preset conductance for controlling the required pressure. Accordingly, the flow out (Q_{out}) is set below the predetermined flow out for the required pressure for a transient period of approximately six and a half seconds. Accordingly, the pressure increases to 2.5 mbar after only about 8 seconds. The length of the transient period is calculated according to the difference between the required pressure and the current pressure, the rate of pressure increase achieved by the initial valve conductance, and the speed of the valve. When C_{valve} has been increased to 50 m^3/hour, the pressure control unit controls C_{valve} to compensate for fluctuations in pressure and to maintain the chamber at the required pressure. The embodiment provides an improvement of about 27 seconds.

In the embodiment illustrated by Figure 4, C_{valve} is reduced to an initial conductance of 10 m^3/hour for a fixed time. The fixed time is slightly shorter than the transient period because the valve takes a finite time to move between positions i.e. from a conductance of 50 m^3/hour to 10 m^3/hour and back to 50 m^3/hour. However, it is not necessary for C_{valve} to be maintained at such an initial conductance value for any length of time, as will be appreciated from Figure 5, which illustrates a variation of the embodiment. In Figure 5, the preset C_{valve} is 57 m^3/hour for achieving a required pressure of 7.5 mbar. C_{valve} is reduced below 57 m^3/hour to 0 m^3/hour and immediately increased to 57 m^3/hour.

Figure 5 shows C_{valve} being reduced to a conductance of 0m^3/hour (valve fully closed) for increasing the rate of pressure increase. A reduction to 0 m^3/hour decreases Q_{out} to zero and therefore the rate of pressure increase is the maximum for this method and becomes:

$$\frac{\partial P}{\partial t}_{MAX} = \frac{Q_{In}}{V_0}$$

However, a reduction in C_{valve} to any value between the predetermined conductance and 0 m^3/hour provides a beneficial increase in the rate at which pressure increases. It should be noted however that it is advantageous to maintain C_{value} at a steady state for a fixed time to ensure better control.

Two variations of the vacuum system shown in Figure 1 are shown in Figures 6 and 7, by way of example. In Figure 6, valve 20 is positioned down-stream of pump 14 and is operable for controlling the effective pumping speed and hence the pressure in chamber 12. In Figure 7, the pump is shown having a high vacuum pump 15 and a backing pump 17, and the valve 20 is positioned between the two pumps and is operable for controlling the effective pumping speed.

A second embodiment will now be described with reference to Figures 8 to 10.

Figure 8 shows a vacuum system of a similar arrangement to that shown in Figure 1. However, in addition to the Figure 1 arrangement, Figure 8 shows a connection 28 between pressure control unit 24 and mass flow controller 26. An increased rate of pressure increase is achieved by an increase in the mass flow of process gas (Q_{in}) into the chamber 12 for a transient period over and above the mass flow of process gas required for processing. The increase in Q_{in} increases the differential flow (Q_{in}-Q_{out}) above the predetermined differential flow for the required pressure. In the example shown in Figure 9, valve 20 is set to the predetermined position for a required pressure of 3.5 mbar. The process gas mass flow rate (Q_{in}) required for processing is two standard litres per minute (slpm). Q_{in} is increased above two slpm for a transient period of about 5 seconds to increase the rate at which pressure increases over the rate at which pressure increases in the prior art as shown by the line superimposed in Figure 9. The length of the transient period is calculated according to the difference between the required pressure and the current pressure, the rate of pressure increase achieved by the initial flow, and the speed of the mass flow controller. Q_{in} is reduced to two slpm to coincide with the pressure in chamber 12 reaching the required pressure. In Figure 9, Q_{in} is increased to 20 slpm where it

is maintained for a period just shorter than the transient period to allow a finite time for the mass flow rate to increase from and decrease to two slpm.

A variation in the method described in relation to Figure 9 is described in relation to Figure 10, wherein during the transient period, Q_{in} is increased to a mass flow rate of 100 slpm and then immediately reduced to 2 slpm. It should be noted however that it is advantageous to maintain Q_{in} at a steady state for a fixed time to ensure better control.

A third embodiment is shown in Figure 11, which differs from the arrangement in Figure 1 in that a connection 30 connects pressure control unit 24 to purge mass flow controller 32. An increased rate of pressure increase is achieved by supplying purge gas (Q_{in}^2) into duct 18 upstream of valve 20 so that the purge gas increases the pressure in chamber 12. Purge gas is supplied for a transient period thereby increasing the differential flow rate ($(Q_{in} + Q_{in}^2) - Q_{out}$) above the predetermined differential flow rate for maintaining the required pressure for processing. The supply of purge gas achieves similar results to those described with reference to Figures 9 and 10.

The embodiments described with reference to Figures 8 to 11 can be adopted alone or in combination with the valve control embodiment as described with reference to Figures 4 and 5. Such a combination of embodiments may be desirable if a very quick increase in pressure is required or if chamber 12 is very large or the mass flow rate for processing is very small. Four examples showing vacuum systems are shown in Figures 12 to 15. Figure 12 differs from Figure 11 in that valve 20 is downstream of pump 14. In Figure 13, purge gas flow controller 32 is arranged to introduce gas directly into the pump 14. Figure 14 shows an arrangement similar to Figure 7 showing two pumps 15, 17. In Figure 14 the purge gas flow controller 32 is arranged to introduce gas directly into the pump 15, and valve 20 is positioned between the two pumps. In Figure 15, purge gas flow controller 32 is arranged to introduce gas upstream of high vacuum pump 15.

A fourth embodiment is shown in Figure 16, which differs from the arrangement shown in Figure 1 in that a connection 34 is made between pressure control unit 24 and a pump inverter 36. Connection 34 enables the pressure control unit 24 to control the rotational speed of the pump 14 and hence the pumping speed (S_{pump}). Valve 20 is omitted from the arrangement. A decrease in S_{pump} decreases the effective pumping speed and therefore increases the rate of pressure increase. Furthermore, decreasing the rotational speed of the pump 14 increases the mass flow rate of gas leaked upstream across the pump (Q_{leak}). Accordingly, the differential flow rate $((Q_{in} + Q_{leak}) - Q_{out})$ is further increased. The embodiment shown in Figure 16, therefore, constitutes a combination of the valve conductance embodiment and the variable inlet gas flow embodiments.

In operation, the pumping speed S_{pump} is decreased for a transient period below a predetermined pumping speed for achieving and maintaining a required chamber pressure. S_{pump} can be decreased below the predetermined pumping speed to an initial preset where it is maintained for a period and then increased to the predetermined pumping speed. Alternatively, S_{pump} can be decreased to a pumping speed and then immediately increased to the predetermined pumping speed. It should be noted however that it is advantageous to maintain pumping speed at a steady state for a fixed time to ensure better control. S_{pump} is increased to the predetermined pumping speed before, or to coincide with, chamber pressure reaching the required pressure. Once the required chamber pressure has been achieved, pressure control unit 24 monitors chamber pressure P and adjusts pumping speed to compensate for pressure fluctuations.

The fourth embodiment can be used in combination with either or both of the embodiments described with reference to Figures 9 and 10, or the embodiment described with reference to Figures 4 and 5.

Variations of the fourth embodiment are shown in Figures 17 and 18. In Figure 17, two inverters are operable for controlling two pumps 15 and 17. In Figure 18, a single inverter is operable for controlling the downstream pump 17 only.

In summary, a method is provided for setting the pressure in a chamber of a vacuum system to a required pressure, the system comprising a pressure control system including a pump for evacuating gas from the chamber and a flow controller for allowing the flow of gas into the chamber. The method comprises setting an initial flow into and/or out of the chamber for achieving a pressure above the required pressure so as to increase the rate of pressure increase, the initial flow occurring over a transient period which does not allow the pressure to exceed the required pressure, and setting a preset flow into and/or out of the chamber after the transient period has elapsed for achieving and maintaining the required pressure.